AN11199

UBA2015 TL Ballast for multiple lamps with independent lamp operation

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Document information

Info	Content
Keywords	UBA2015, tube lamp (TL), Independent lamp operation (ILO)
Abstract	This application note describes how to drive multiple lamps with a UBA2015 so that when one lamp fails the other lamps keep burning.

Revision history

Rev	Date	Description
v.1	20121224	first issue

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1. Introduction

There are several topologies possible for multiple lamps. The topology chosen depends on the Bill Of Materials (BOM) and the requirements. Table 1 shows the topologies for independent Tube Lamp (TL) operation described in this document.

Table 1. Topologies for independent TL operation

Topology	Pros	Cons	Ballast Efficacy Factor (BEF)	Independent lamp operation (ILO)
One resonant tank per lamp	simple architecture	one inductor per lamp needed	0	full
One resonant tank per two lamps (two by two lamps in series)	less magnetic and half-bridge current	if one lamp fails, then two lamps are off	+	half
All lamps on one resonant tank	separate heating transformer delivers short preheat and high BEF	more complicated control circuit	++	full
All lamps on one resonant tank with transformer	instant activation	no preheat	++	full

Remark: All topologies are free of patents.

2. Overview of Commonly Used Topologies

This application note uses four 18 W T8 lamps as an example. Some of the topologies also apply to T5 lamps.

2.1 Topology 1: four lamps in parallel with four resonant tanks

Figure 1 shows a topology of four lamps in parallel, each with a resonant tank. Only the resonant tank part is shown. The PFC section design generating the bus voltage does not depend on the ballast topology and is therefore not shown.

The advantage of this topology is that it is true ILO, that is, the ballast works with one, two, three or four lamps inserted. The main disadvantage is that four rather expensive inductors are needed. This topology has the capacitor through the filaments, so it is not suitable for the T5 Hawaiian Electric Industries series of lamps.

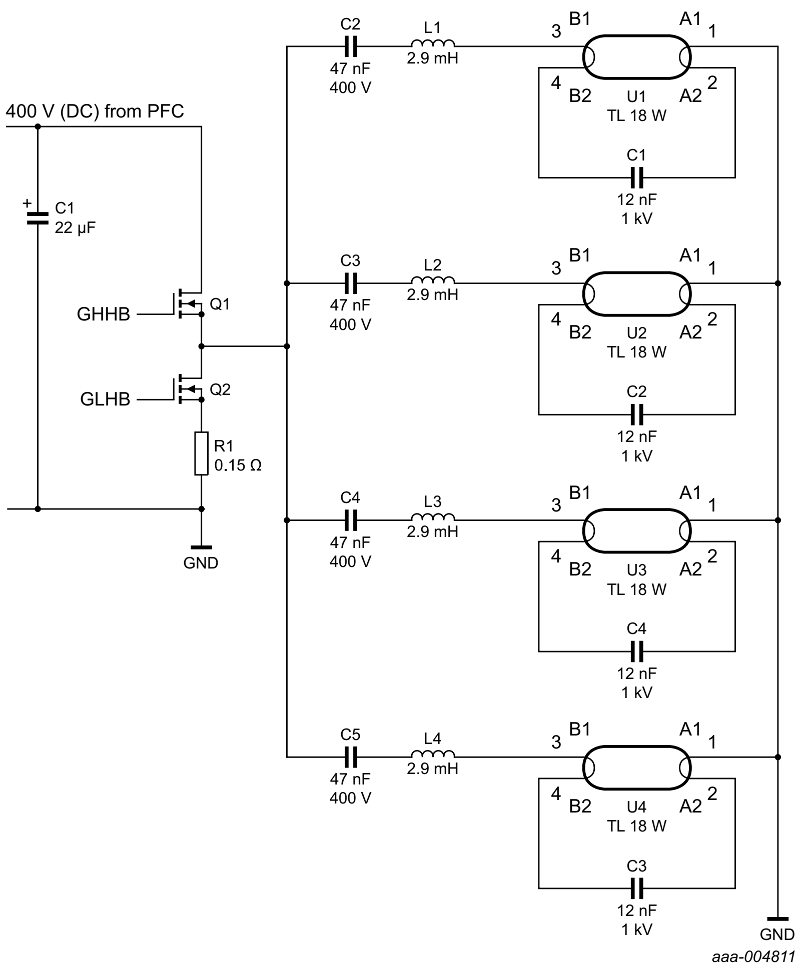


Fig 1. Four lamps in parallel with four resonant tanks

2.2 Topology 2: two × two lamps in parallel with two resonant tanks

Figure 2 shows a topology that only requires two inductors. It is therefore, cheaper and has fewer losses than topology 1.

The current through the MOSFETs is also lower, reducing the losses/BOM cost even further. The only disadvantage of this topology is that if one lamp is missing or broken, two out of four lamps do not burn.

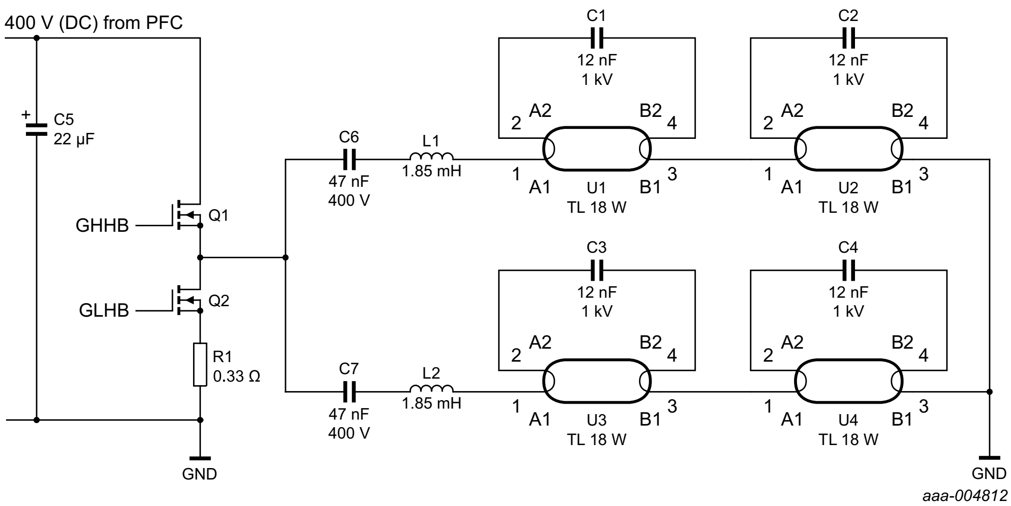


Fig 2. Two × two lamps in parallel with two resonant tanks

2.3 Topology 3: four lamps in parallel with one resonant tank

The topology shown in Figure 3 allows full ILO (one, two, three or four lamps) but has a larger BOM and is more complex.

The resonant capacitors cannot now be placed over the lamp so some form of inductive heating must be used if preheat is required. This heating allows this topology to be used for T8 and T5 lamps. The inductive heating can be switched off after preheat with an extra MOSFET.

To enable optimal operation, a feedback control loop is required. This loop keeps the lamp discharge current constant regardless of the number of working lamps in the ballast.

If relamp is required, place a DC blocking capacitor in series with the inductive filament heating windings. A simple, one transistor circuit can generate a reset pulse if a lamp is inserted.

Inductor L1 carries the current of the lamps in parallel, plus the resonant tank current. This voltage is large due to the 200 V to 300 V voltage on the resonant tank capacitor during lamp operation. Inductor L1 is therefore bulky/expensive, partially undoing the benefit of having only one resonant tank inductor instead of four.

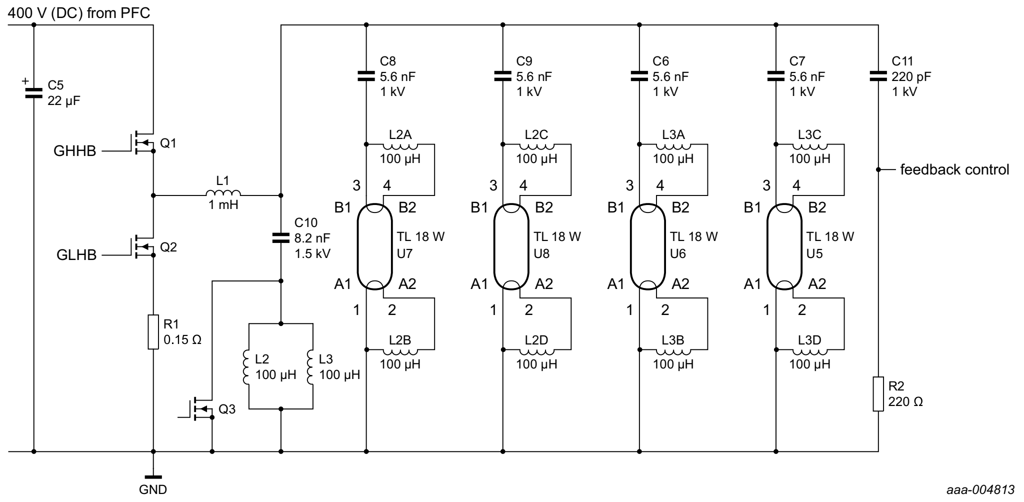


Fig 3. Four lamps in parallel with one resonant tank

Figure 3 shows a topology with a current transformer in the resonant tank. A separate heating transformer is also commonly used, as shown in Figure 4.

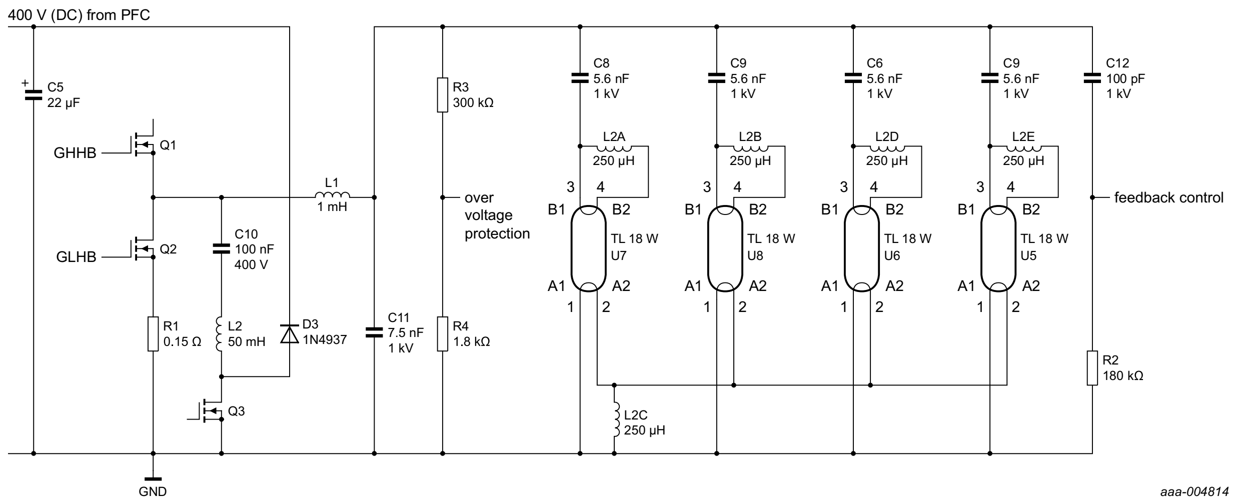


Fig 4. Four lamps in parallel with one resonant tank with a separate heating transformer

The heating transformer is switched off after preheat with a MOSFET or a PTC. Heating with this separate transformer, directly on the half-bridge, is known as voltage mode (constant secondary current). Heating with the transformer in the resonant tank is known as current mode (constant secondary current).

A separate heating transformer provides a shorter preheat time and a lower filament current during lamp operation. Less filament current (the Sum of Squares (SoS) of the current) means a higher efficiency (BEF).

2.4 Topology 4: two × two 18 W lamps with one resonant tank

The topology shown in Figure 5 has only one inductor, but the current through it is lower (800 mA RMS for four 18 W T8 lamps).

The relamp, which is easier to implement, can be combined for two lamps at a time. The downside is that it is only half ILO, so that if one lamp fails then the other lamp in series with it also fails.

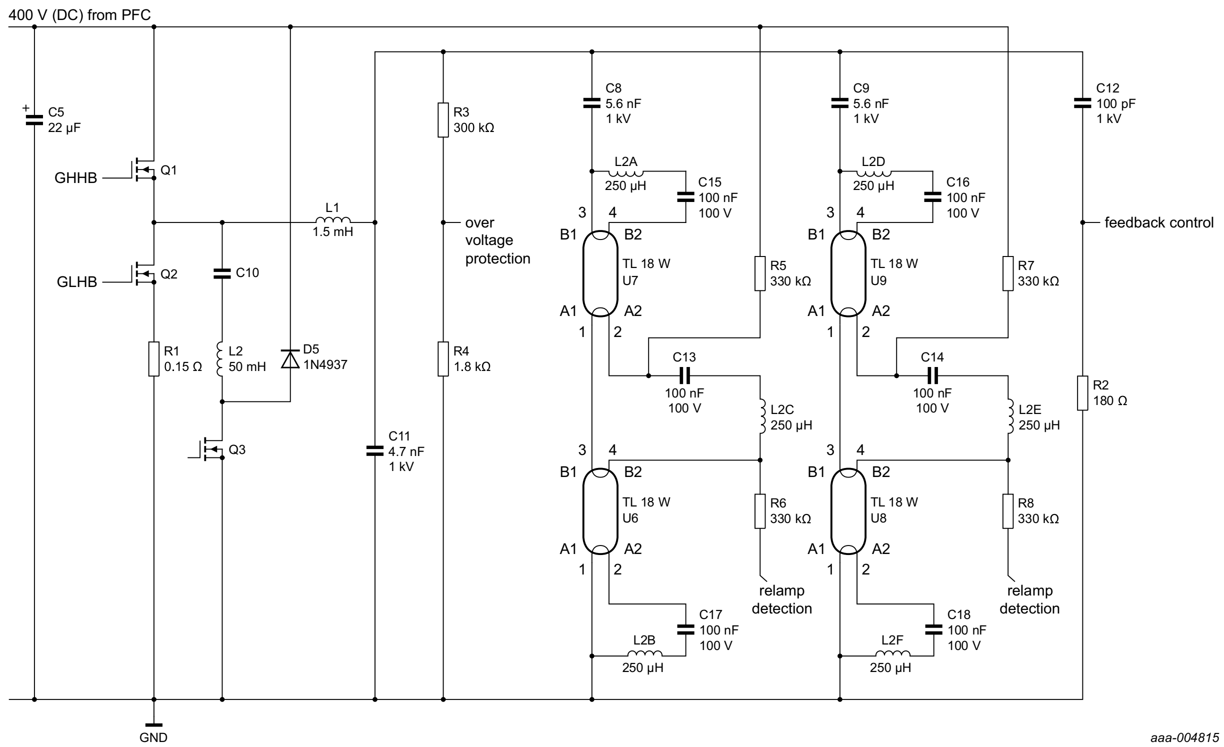


Fig 5. Two × two 18 W lamps with one resonant tank

2.5 Topology 5: 4 lamps with transformer

Figure 6 shows the LLC topology.

The main advantage of this topology is that there is always a very high voltage over the output of the transformer (1 kV). This high voltage ensures that if a lamp is inserted it ignites immediately. There is no need for extra circuits to restart the ballast on lamp insertion (relamp).

This high voltage is not allowed during lamp operation in many countries outside the USA. The transformer is also a rather bulky/expensive magnetic component.

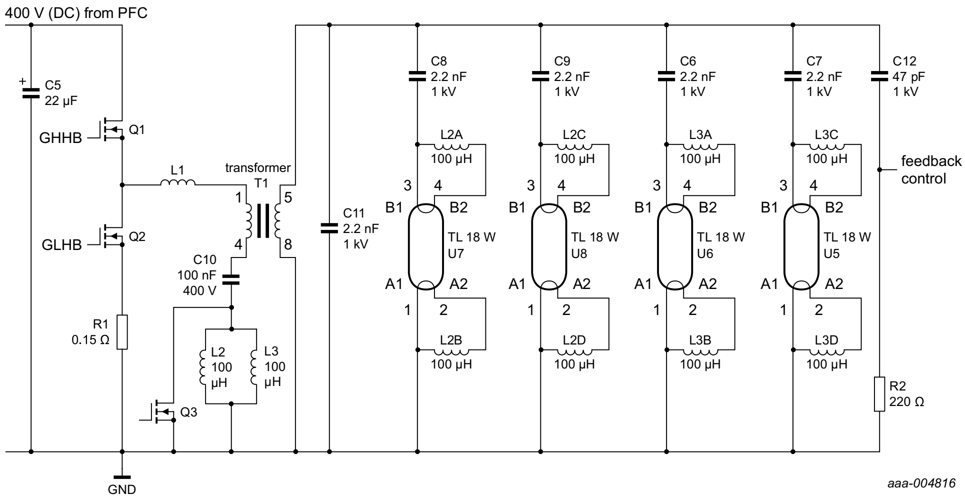


Fig 6. Four lamps in parallel with transformer

2.6 Topology 6: Inductive heating with added circuit

The problem with inductive heating is that a resonant tank is always required, even if the lamp is not present. This resonant tank causes a too high voltage if there is no lamp inserted at the ramp down of the frequency to f_{min} after preheat. Therefore, to operate correctly, the ballast must be at standby to lower the frequency to less than the ignition frequency for the other lamps.

If the two resonant tanks are coupled with a capacitor, the ballast controller can continue to ramp down its frequency to f_{min} if one lamp does not ignite. However, this coupling results in an approximate doubling of the lamp current for the lamp that is working at f_{min}.

To avoid this situation, add a high current a sense resistor for each lamp. The UAB2015 feedback control system can then use the maximum of either of the currents. With only one lamp inserted/working, the system runs at about 55 kHz instead of the nominal 45 kHz.

Figure 7 shows inductive heating with added circuit.

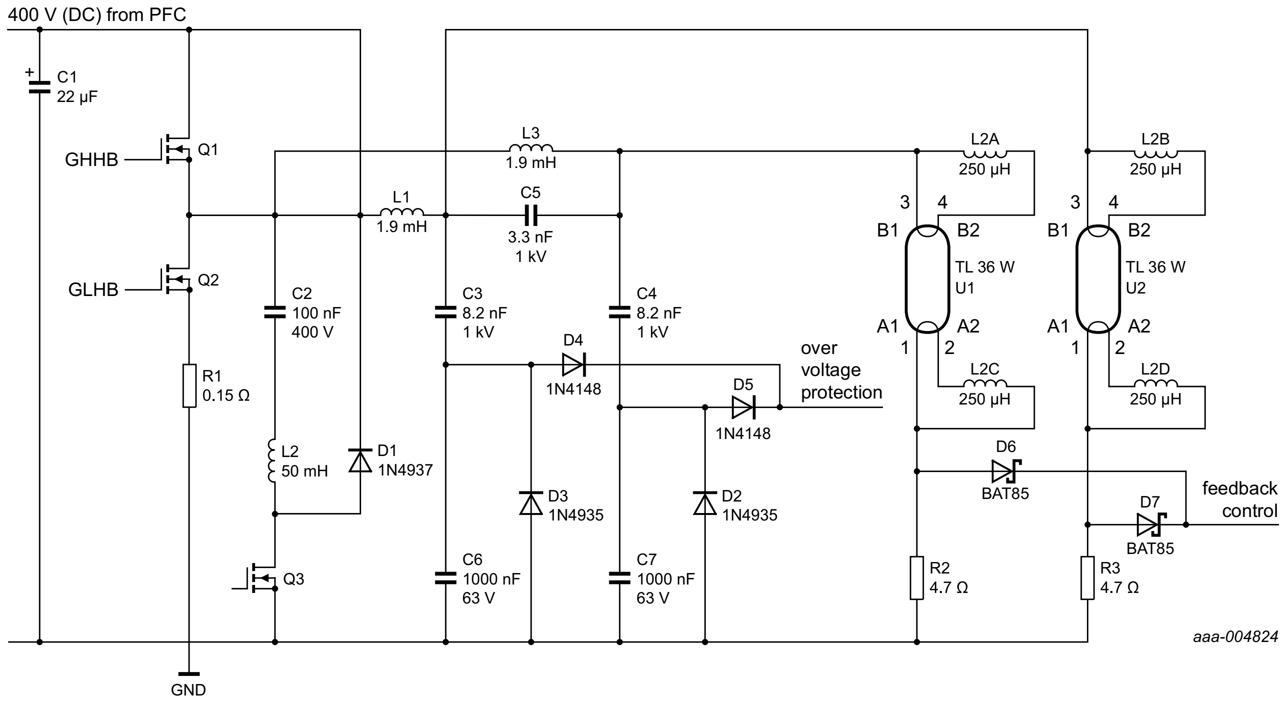
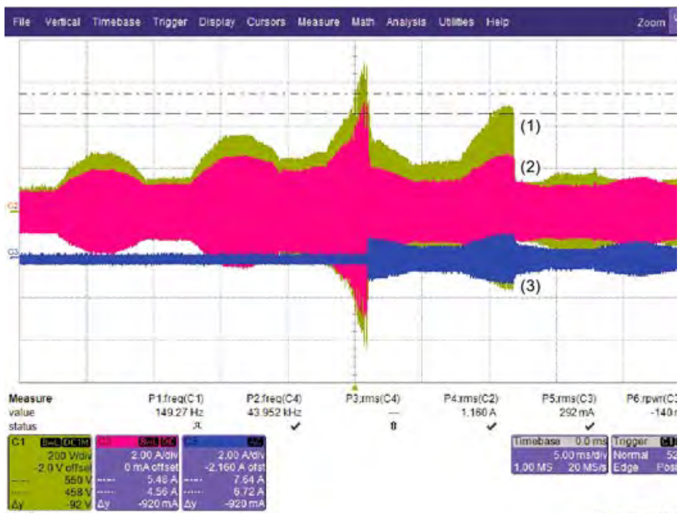


Fig 7. Inductive heating with added circuit

As shown in Figure 8, the voltage over the other ramp first drops because, a capacitor is effectively added to its resonant tank.



(1) Voltage over lamp 1

(2) Total half-bridge current

(3) Current through lamp 1

Fig 8. UBA2015 ILO TL ballasts

At a lower frequency, the resonance point of this new tank is reached and the second lamp ignites. The UBA2015 family has a delay of 5 ms between the first ignition detect and the start of the control loop. This delay is sufficient time to ignite a second lamp while not overstressing a lamp if it is the only one present.

This coupling is only possible for non-dimmable systems. If two different brands of lamps are inserted, a small imbalance in lamp power (<1 W) can occur. For example, 31.5 W and 32.5 W instead of two times 32 W. The average power stays the same.

2.7 18 W T8 and T5 lamp types

The following sections provide design examples for T8 18 W lamps. These lamps are commonly used in a four lamp configuration (making a square sized tile on a ceiling).

There is a problem with this lamp type. It is not possible to use one capacitor through its filaments and have acceptable preheat together with good lamp operation (high BEF). The same applies to the T5 Hawaiian Electric Industries series of lamps.

The T5 Hawaiian Electric Industries series of lamps cannot use the topologies with a resonant capacitor through its filament. Choosing the right topology and implementing an ILO ballast is not an easy task. The local NXP Semiconductors sales office can provide support.

3. ILO two × two 18 W lamps and ballast with ceramic disk capacitors

This section describes the implementation of a complete ILO ballast for four T8 type 18 W lamps. This design follows that of topology 2 which is described in Section 2.2.

The ignition of two lamps in series with resonant capacitors is not as straightforward as expected. Without these capacitors both lamps must ignite together to produce a conducting path. With capacitors, they can ignite one after another. With neither of the lamps ignited, the resonant tank is as shown in Figure 9.

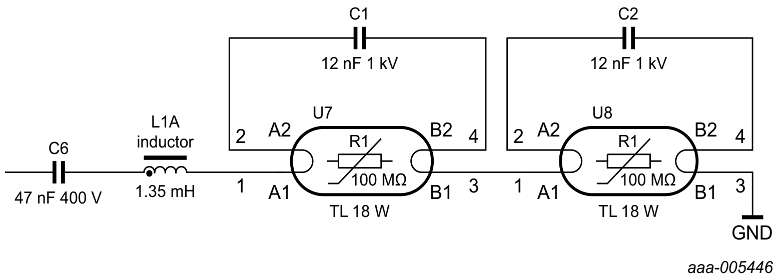


Fig 9. ILO Two × two 18 W lamps with ballast with ceramic disk capacitors

The effective capacitance of the resonant tank is 12 nF/2 = 6 nF. Its resonant frequency with a 1.95 mH inductor is 50 kHz as shown in Figure 10.

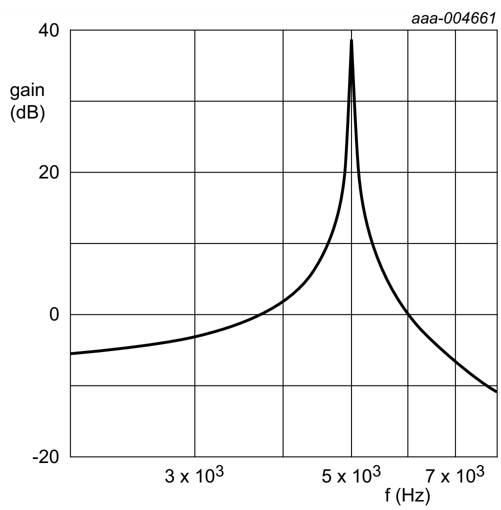


Fig 10. Transfer function, no lamps ignited

When one of the lamps ignites, its resistance becomes 55 V / 300 mA = 183 Ω. This value is only an indicative value and the real value is a little different immediately after ignition. This resistance provides a new resonant tank. The tank consists of a capacitor for the not-ignited lamp and a 183 Ω resistor in parallel with it for the ignited part.

With a 12 nF resonant capacitor, this new tank has a resonant frequency of around 42 kHz. This second resonant frequency is reached during the ignition ramp-down. If not, then only one lamp stays on.

Ignition of two lamps in series is simultaneous, or 20 ms after each other, during the ramp-down to the minimum frequency of the ballast. After the first lamp ignites, the transfer function is similar to the one shown in Figure 11.

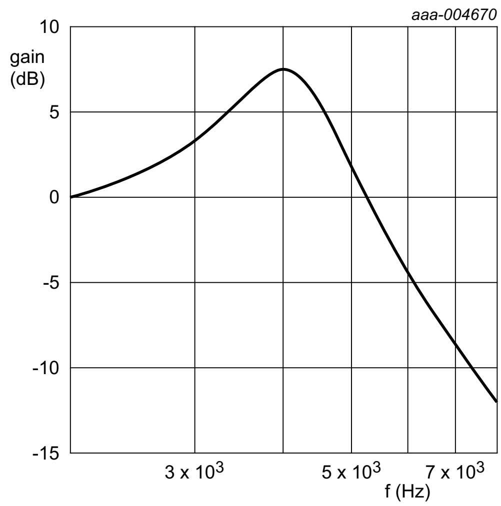


Fig 11. Transfer function, first lamp ignited

3.1 Preheat and filament current during lamp operation

In constant current mode, the T8 18 W lamp needs more than 500 mA for 1.7 s preheat.

Table 2. TL-D 18 W preheat and filament current during lamp operation

Preheat current (mA)	Preheating time				R_{SUB} (Ω)
	0.5 s	1 s	1.5 s	2 s	
minimum	785	600	525	485	7.5
maximum	985	660	660	605	9.5

To provide for a proper preheat around 50 kHz, the T8 18 W needs 12 nF or more of resonance capacitance. This capacitance is required to produce the preheat current without early ignition. This requirement is because the T8 18 W allows only 200 V across the lamp during preheat.

At 40 kHz, 55 V lamp voltage and 12 nF the filament current through the capacitor is:

$$2 \times \pi \times f \times V_{lamp} \times C = 165\ mA \quad (1)$$

Every lamp has an optimal sum of squares (SoS) of the filament currents.

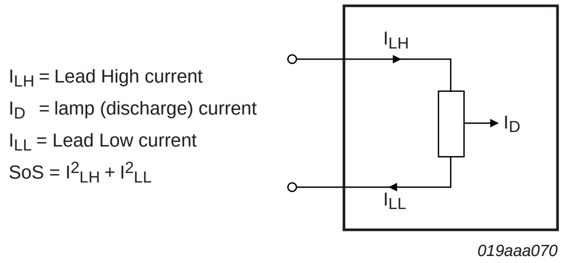


Fig 12. Sum of squares (SoS) of the filament currents

The target SoS at a nominal operation of 290 mA discharge current is 0.164. With a discharge current of 290 mA and a capacitor current of 165 mA, I_{LH} is 335 mA. This current gives an SoS of 0.15.

Even though this current is still under the SoS target, the filament losses in the total system are very large. These losses are due to the fact there are eight filaments for a ballast of only 64 W. Therefore, with 12 nF, the BEF of the ballast is too low.

Table 3. TL-D 18 W electrode currents during lamp operation

	$I_{D(min)}$ (A)	$I_{D(max)}$ (A)	$I_{LH(max)}$ (A)	$I_{LL(max)}$ (A)
Normal operation	0.280	0.450	0.480	0.360
Dimming operation	0.035	0.280	0.480	0.360

Table 4. SoS of the TL-D 18 W electrode currents during lamp dimming operation

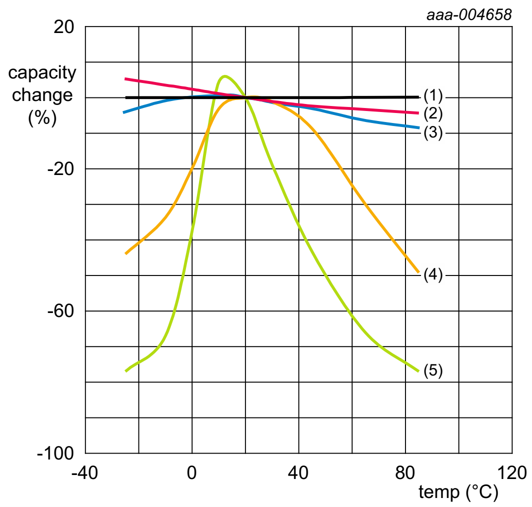
	X_{min} (A^2)	Y_{min} (A)	X_{max} (A^2)	Y_{max} (A)
$SoS_{min} = X_{min} - Y_{min.ID}$ $SoS_{target} = X_{min} - Z \times (Y_{min.ID})$ $SoS_{tmax} = X_{max} - Y_{min.ID}$	0.220	0.640	0.260	− 0.160

Z = 0.3

To improve the BEF, use ceramic disk capacitors such as the Murata E class capacitors. These capacitors lose a part of their value at a higher ambient temperature.

This temperature effect of ceramic disk capacitors is commonly used in the lighting industry (mostly in CFL). At a nominal operating temperature of 70 °C these capacitors lose 40 % of their value, so are only 7 nF.

This value reduces the SoS and increases the BEF of the ballast. The SoS is still greater than SoS_{min}.



(1) CH
(2) SL
(3) B
(4) E
(5) F

Fig 13. CH, SL, B, E, F characteristics

3.2 Schematic diagram of two × two 18 W UBA2015 ballast

If a lamp is removed, the lamp in series with it also stops working. If a lamp stops working but still has its filaments in place (de-gass), the other lamp keeps on working. In this case, the discharge current flows through the capacitor of the other lamp.

To reset the ballast when a lamp is inserted (relamp), add a small lamp insertion detection circuit.

If rectification of one of the lamps occurs, the ballast goes to standby (rectification is rare, so the ballast is ILO for most normal usage).

Figure 14 schematic diagram of two × two 2 18 W UBA2015 ballast.

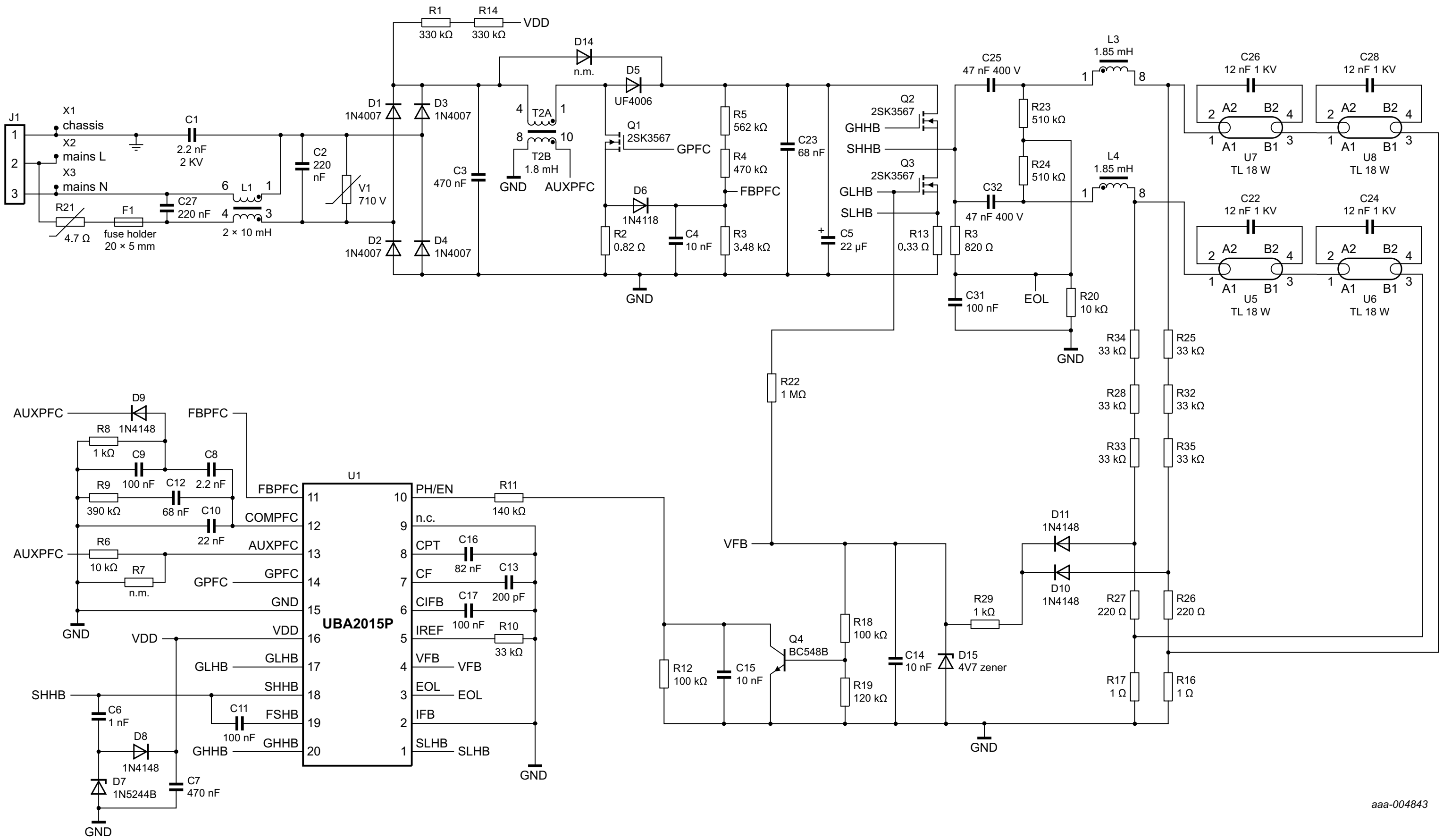


Fig 14. Schematic diagram of two × two 2 18 W UBA2015 ballast

3.3 PFC

A complete explanation of the PFC section is contained in the *UBA2015 application note*, which can be found on the NXP Semiconductors website.

A relatively low PFC voltage of 375 V is generated. This voltage ensures that with two times 12 nF in the resonant tank and a minimum frequency of 42 kHz, the second lamp ignites. It also ensures that the nominal discharge current is 280 mA.

With a 450 V bus voltage and 48 kHz operating frequency, it is possible that one of the two lamps does not ignite. The optimum is to be on the second ignition frequency, such that both lamps always ignite and stay on (reignite if one has a short hiccup).

3.4 EOL rectification protection

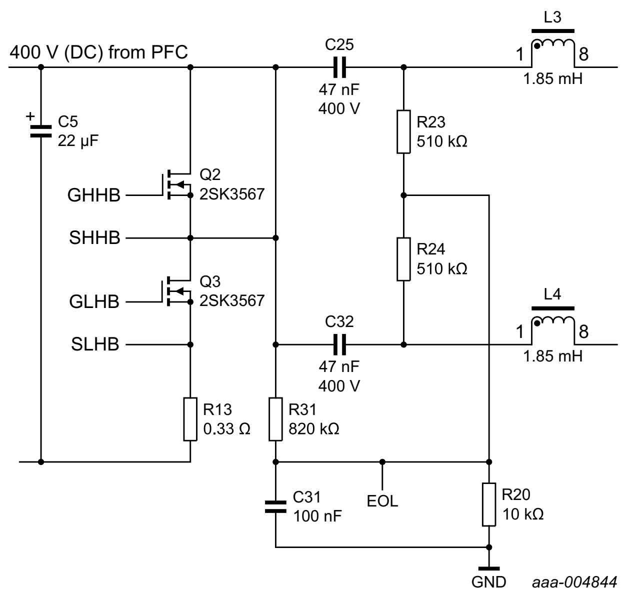


Fig 15. EOL rectification protection

The UBA2015 IC has a lamp rectification window detector of 1.9 V. The resistors R31, R30 and R20 are therefore given values so that at no-rectification there is 1.9 V on the EOL pin.

Since there is only one EOL pin, the voltage of both branches is mixed. If one branch is not operational (missing lamps), then there is no false detection. Lamp rectification detection is not mandatory for T8 lamps, so the circuit could be left out. However, the DC blocking capacitors C25 and C33 must then be 600 V instead of 400 V.

The EOL detection triggers at an asymmetrical power greater than12.5 W.

3.5 Voltage feedback and preheat circuit

As shown in Figure 14, the lamp voltage and (preheat) current are mixed using diodes D10 and D11 and fed to the VFB pin. This pin regulates the frequency during preheat so that the voltage on it remains below 2.5 V.

During lamp operation, the voltage must stay below 0.8 V. If one of the lamps is not present, the current and voltage mix must stay below this 0.8 V. When there is no ignition (de-gass), the VFB voltage remains at 2.5 V for 150 ms.

When the external components that make this VFB voltage are included, there is approximately 1400 V across the lamps. The ballast then executes one retry and, if there is still no ignition, it goes to standby.

3.5.1 Preheat circuit

The same current/voltage feedback signal is used to regulate the voltage across the lamps during preheat. The 12 nF ceramic disk capacitors can have a lower value for a restart, with an environment temperature of 70 °C (on/off/on cycle). Therefore, the maximum preheat voltage is limited using transistor Q4.

The only downside is that, in this case, the preheat current can be a little lower than specified. During typical use of a TL ballast, this lower current does not affect the lamp lifetime. If the environment temperature is higher, the diodes D10, D11 and transistor Q4 have a lower drop (2 mV / K).

In summary, about 350 mA to 400 mA preheat current remain in the case of a warm restart.

3.5.2 Fine-tuning the total system

The ceramic disc capacitors are the key here; different brands give different results. It is possible to mix ceramic disk and film capacitors. For example, a 8.2 nF ceramic disk with a 3.9 nF film capacitor has little temperature variation.

Once the capacitors are chosen, the rest of the component values are easily fine-tuned to provide optimal ballast performance.

4. Four 18 W lamps in parallel using separate heating transformer

Another way to make the ballast is using inductive heating with four lamps in parallel. The resonant tank in this example design is similar to the one shown in topology 3 (Section 2.3).

Figure 16 shows four lamps in parallel with separate heating transformer.

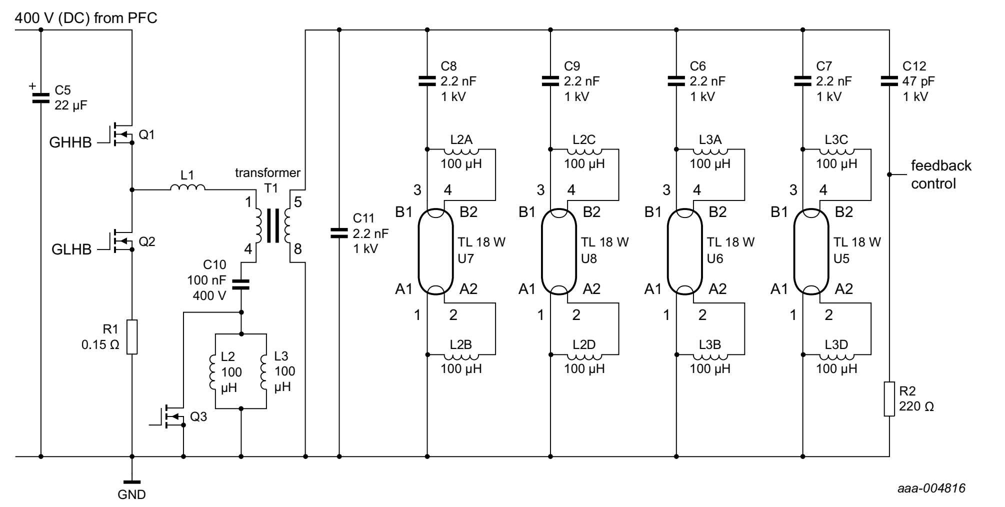


Fig 16. Four lamps in parallel with separate heating transformer

The resonant tank consists of inductor L1 and resonant capacitor C11. During lamp operation, there is a voltage of approximately 300 V RMS over C33. The load consists of one to four lamps using series capacitors.

4.1 Filament Preheat using a heating transformer

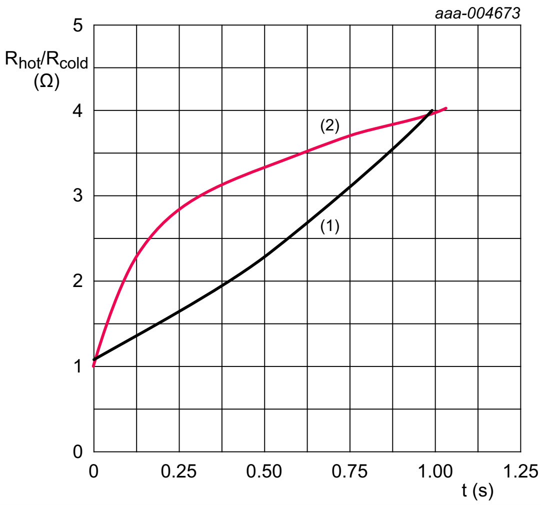
The ballast with preheat at a relative high frequency uses a separate heating transformer T2.

The heating transformer switches off after the IC controlled preheat ends. It can also be switched off, about 50 ms earlier, after the ignition voltage is applied. The transformer is relatively small and without an air gap. The circuit to switch it off must have low capacitance to avoid current flowing through it during lamp operation.

Since the transformer acts as a voltage transformer, the constant voltage preheat table of the lamp applies, that is the one for T8 18 W.

Table 5. TL-D 18 W constant voltage preheat

Preheat voltage (V)	Preheating time				R_{SUB} (Ω)
	0.5 s	1 s	1.5 s	2 s	
minimum	5.9	4.5	3.9	3.6	7.5
maximum	9.3	7.2	6.3	5.8	9.5



(1) Current 460 mA

(2) Voltage 3.8 V

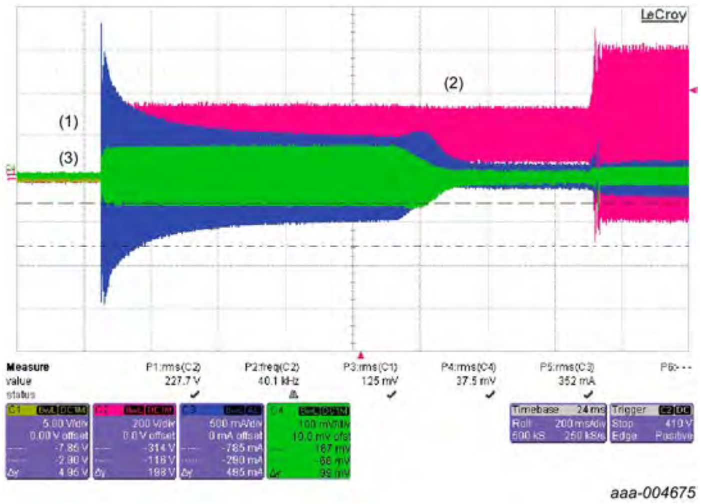
Fig 17. Resistance ratio R_{hot}/R_{cold} versus time

The advantage of constant voltage preheat is that the preheat time can also be a little longer without much affect on filament temperature. Figure 18 shows the preheat phase with the ignition deliberately delayed.

To reduce the inductive current during lamp operation, place a capacitor over transformer T2. To increase the inductive current, place a capacitor over the MOSFET that switches transformer T2.

The discharge current splits itself over the wires. Therefore, the SoS can be lower than SoS_{min}, the SoS where the filament resistance is about 4 × R_{cold}. This split is not 50/50, as it depends on the hotspot position.

Therefore, C40 is optional. Also, depending on the choice of MOSFET for Q5, an extra (22 pF to 47 pF) capacitor is placed over the MOSFET. This addition keeps the filament at a good operating temperature.



(1) Preheat current

(2) Voltage over the lamps

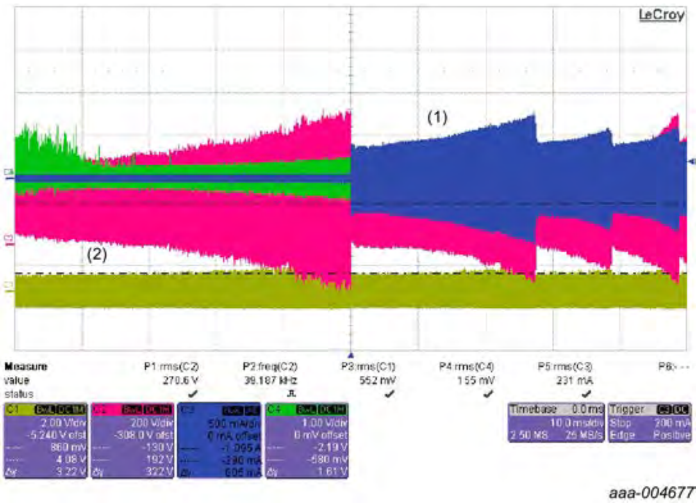
(3) Voltage over filaments

Fig 18. Preheat phase with the ignition deliberately delayed

4.2 Ignition sequence of four lamps in parallel with this topology

In theory, the lamps ignite one by one in the sweep down from the preheat frequency to the minimum frequency. Every time a lamp ignites, the voltage over the resonant capacitor (C11 in Figure 16) drops. The frequency then falls until the next resonant tank point is reached.

The sequential ignition is shown in Figure 19. Every time a lamp ignites, the new resonant frequency of the total system becomes lower.



(1) Current through one of the lamps

(2) Voltage over the resonant tank

Fig 19. Ignition sequence

Equation 2 shows the formula for the resonant frequency of the LRC series in Figure 19.

$$\omega_O = \left(\sqrt{\frac{1}{LC}} - \frac{1}{(RC)^2}\right) \quad (2)$$

The more lamps ignite the higher the load (the lower the resistance R) becomes.

The ramp down-time of the UBA2015 for ignition is less than 50 ms so the lamps appear to ignite at the same time.

After the ignition of four lamps the ballast runs at the minimum frequency. The CF capacitor, giving about 280 mA discharge current through each lamp, sets this frequency. This situation is the normal case with four lamps and no lamps failing to ignite.

The current through the inductor L3 is 1.7 A RMS, therefore the inductor is made of thick wire to minimize losses.

4.3 Independent lamp operation (ILO) in this topology

This design is meant for ILO, therefore it must also work with only one, two or three lamps inserted.

If one of the lamps does not ignite, or is missing, the voltage over the resonant tank can rise to 3 kV or until something breaks. At about 1 kV (sufficient for T8 18 W lamp ignition), the ramp-down to the minimum frequency stops and the UBA2015P feedback control loop starts.

The UBA2015P feedback control loop starts within 2 ms to 4 ms after the following conditions are met:

- The voltage on the CSI pin is >1 V
- The voltage on the VFB pin is < 1 V

The feedback control loop must not start too quickly. Then only one or two lamps ignite and the UBA2015P control loop must increase its frequency to enable the other lamps to ignite. If the minimum frequency is reached, the feedback control loop starts anyway.

The feedback control path activates a capacitor and a resistor connected in series to the resonant tank. A circuit converts this voltage into a DC level for the UBA2015P CSI input.

The four lamp branches also consist of a capacitor and resistor (lamp) in series. The feedback control mechanism must match this voltage to draw a constant lamp current, independent of the frequency the ballast is running.

The sense resistor (R2 in Figure 16) chosen must enable the use of four lamps without activating the feedback control loop.

The ballast runs on f_{min} with a discharge current of 280 mA, which is the recommended value for a T8 18 W lamp. With less than four lamps, the feedback control loop is active and a discharge current of 300 mA runs through the remaining lamps. This activation is done deliberately to avoid having too many critical components for the lamp current in normal usage.

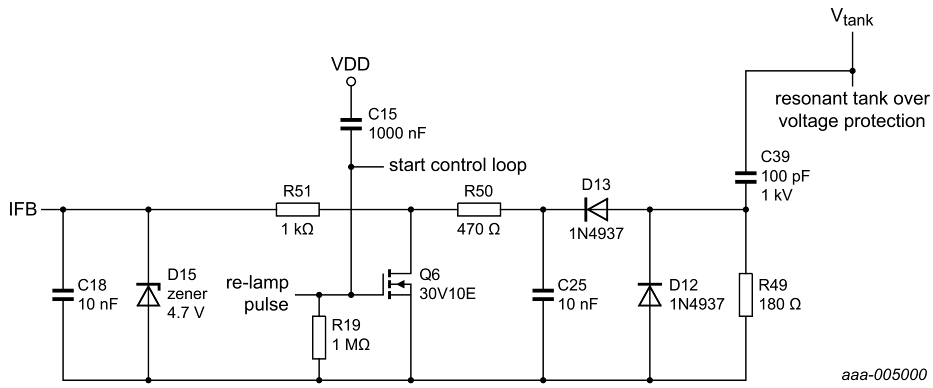


Fig 20. Lamp current control

Remark: Place C18 and R51 close to UBA2015 to provide line reflection reduction.

The signal from the sense resistor enters the circuit in Figure 20 from the right. It is then converted into an IFB level for the feedback control loop.

The small signal MOSFET Q6 (30 V, 20 E) conducts from start-up until a specific time. C15 and R19 set this time. This time is longer than the IC preheat time. It disables the control loop and makes sure that the UBA2015 is at its minimum frequency before the control loop starts.

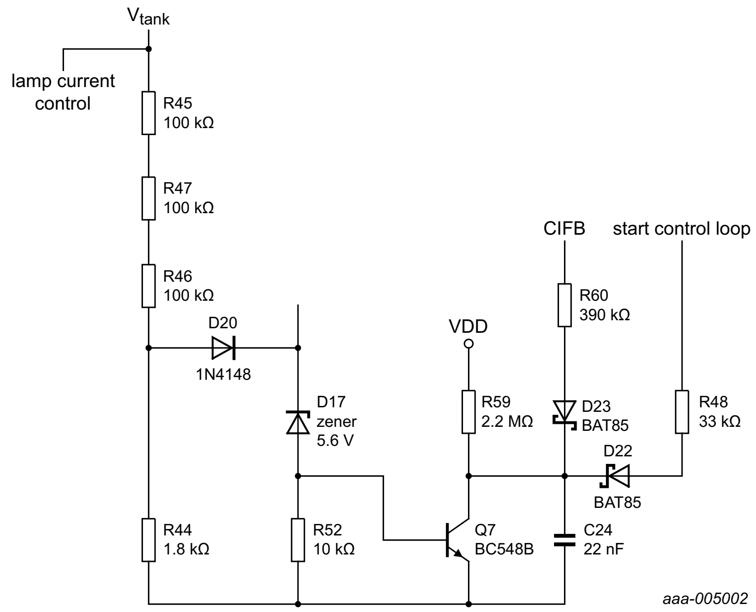


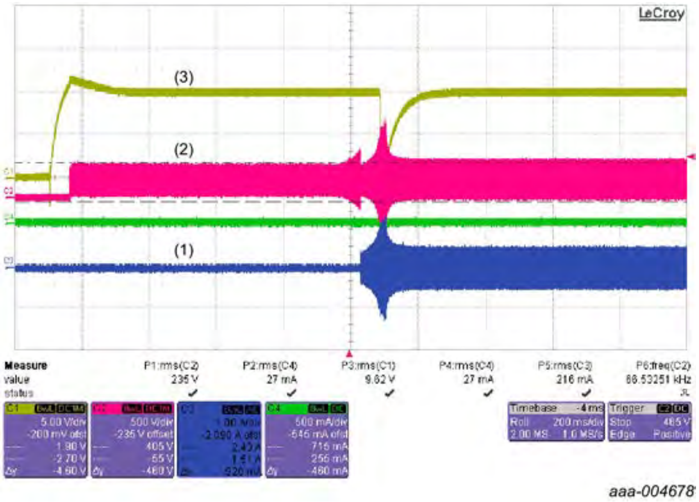
Fig 21. Resonant tank Overvoltage protection

However, if the resonant tank voltage becomes greater than 1000 V (the normal T8 18 W lamp ignition voltage) the feedback control loop is activated. This activation is achieved by switching off Q6 using transistor Q7 and resistor R59.

Normally, the VFB pin is used to prevent over voltage. Here however, this pin cannot be used because it prevents the control loop from starting. Therefore, in the proposed circuit the resonant tank voltage is divided with resistors and a small current pulled from the CIFB pin with a transistor.

The voltage on the CIFB pin provides the input of the VCO and determines the running frequency of the ballast. So, R60 limits the frequency ramp-down to approximately 1 kV, which is more than enough to ignite a T8 18 W lamp. At the same time, the IFB pin is released (greater than 1 V). Within 2 ms to 4 ms, the control loop starts and the frequency increases to produce a good discharge current from the lamps that are present.

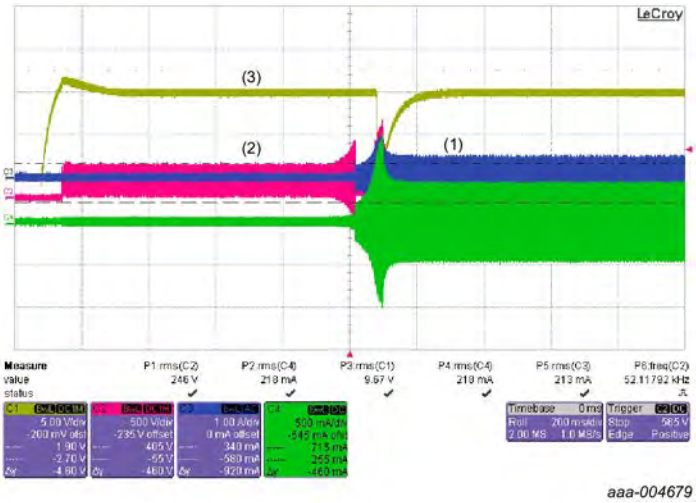
Figure 22 shows the preheat and ignition with only one lamp inserted. If the voltage on the resonant tank reaches a too high value, the frequency ramp-down stops and the feedback control loop starts.



(1) Discharge current of the only lamp
(2) Voltage over the resonant tank
(3) Voltage on NPN transistor Q7

Fig 22. Preheat and ignition with only one lamp inserted

The plot for two lamps is shown in Figure 23. Two lamps can ignite at the same time, so four ignition peaks cannot always be seen when four lamps are inserted.



(1) Discharge current of the only lamp
(2) Voltage over the resonant tank
(3) Voltage on NPN transistor Q7

Fig 23. Preheat and ignition with two lamps inserted

4.4 No lamps

If there are no working lamps present, the ballast is able to keep running on a frequency of 10 kHz. This frequency is approximately the ignition frequency of the resonant tank.

This situation is also possible if the final lamp stops working during lamp operation. In that case, the resonant tank voltage is approximately 200 V. This voltage is within the IEC safety limits and any power loss is minimal. Under these circumstances, the ballast can run indefinitely without any damage. However, switching the ballast off is recommended.

Switch-off is achieved using a transformer (toroid). The transformer senses when there is no lamp current within a few seconds of start-up and switches the ballast to standby.

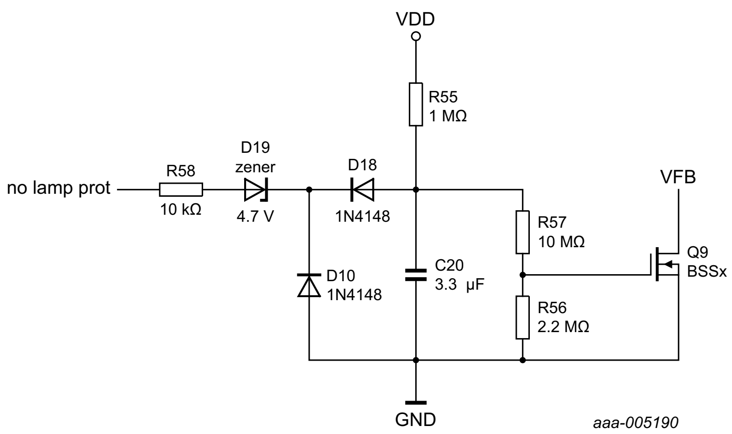
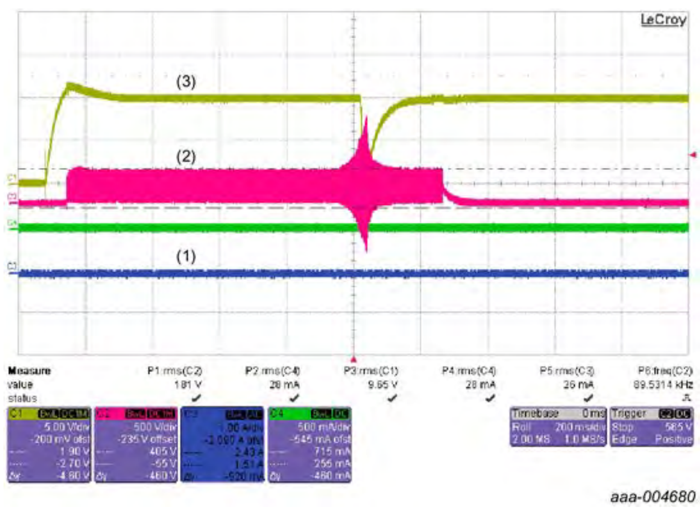


Fig 24. Optional no lamp protection

Start-up with no lamps causes the system to go to standby as shown in Figure 25. However, a running system with only one lamp ignited continues running if the lamp stops working during operation.



(1) Discharge current of the only lamp

(2) Voltage over the resonant tank

(3) Voltage on NPN transistor Q7

Fig 25. Preheat and ignition with no lamps inserted

4.5 Coil saturation protection

If the inductor saturates during ignition, the UBA2015P switches the ballast into standby within a few cycles, thus avoiding damage to the half-bridge MOSFETs. However, the size of the inductor must remain limited.

Therefore, a support saturation regulation circuit inside the UBA2015P is used before the protection kicks in. With a diode over R_{sense}, the remainder of the half-bridge cycle is aborted, effectively increasing the frequency. Diode D21 (see Figure 26) is required to prevent a negative voltage on the CF pin.

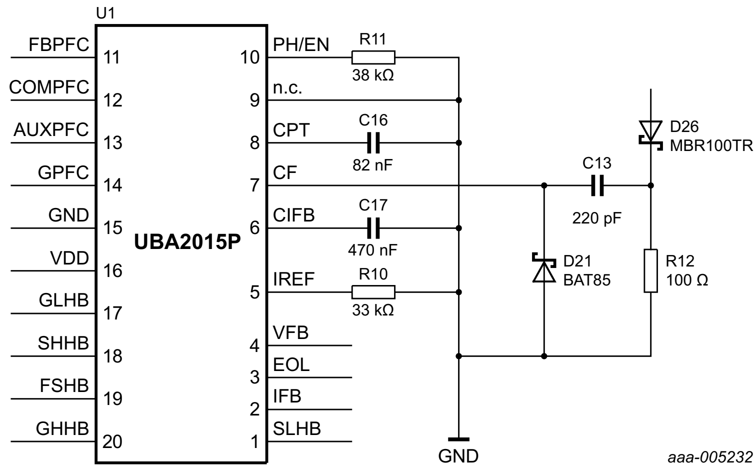


Fig 26. Coil saturation protection

The I_{sat} of the inductor must greater than 5 A. With three lamps already ignited at the ignition voltage of the last lamp, these lamps conduct a discharge current of about 700 mA per lamp. This discharge is also present if only three lamps are inserted at the maximum voltage of 1 kV).

Some trade-off can be made here by reducing the series capacitors (now 5.6 nF) and the nominal voltage on the resonant tank (now 300 V RMS).

4.6 Relamp

If a relamp circuit is added, the inductive heating must have a capacitor in series with the heating transformer secondary winding to allow filament detection. The other filament contact is connected to ground.

One small signal transistor can short-circuit IFB for 50 ms to return the ballast to its minimum frequency and ignite the newly inserted lamp.

In the circuit in Figure 27, if a lamp is inserted the voltage over the 1 nF capacitors (V_{DD}) falls to almost zero volts. This drop causes a short pulse through R61 which, in turn, opens PNP transistor Q10.

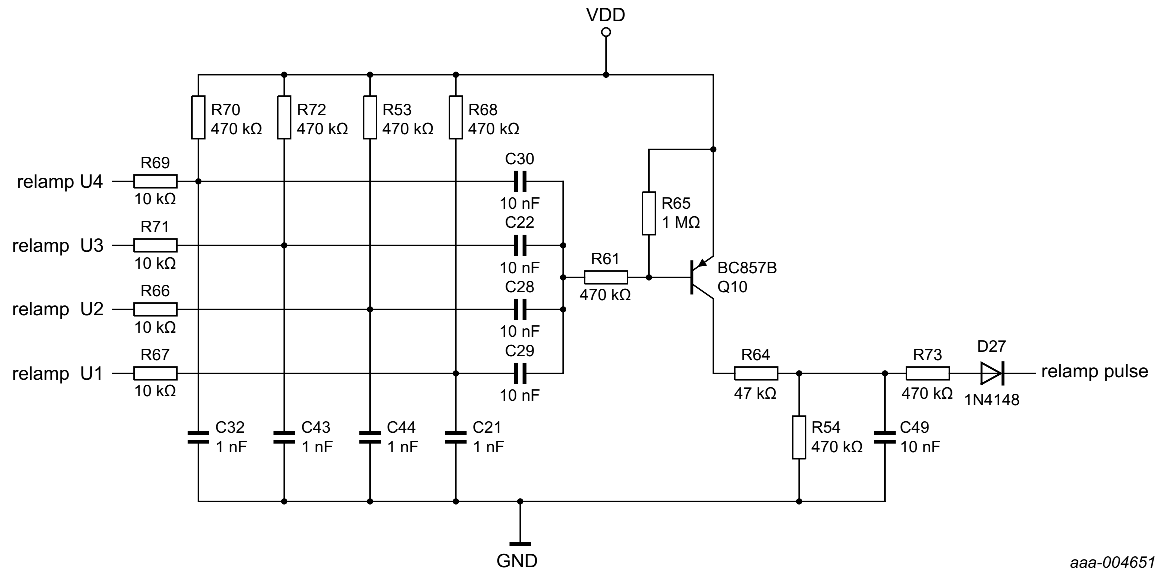


Fig 27. Relamp detection 1

4.7 EOL rectification protection

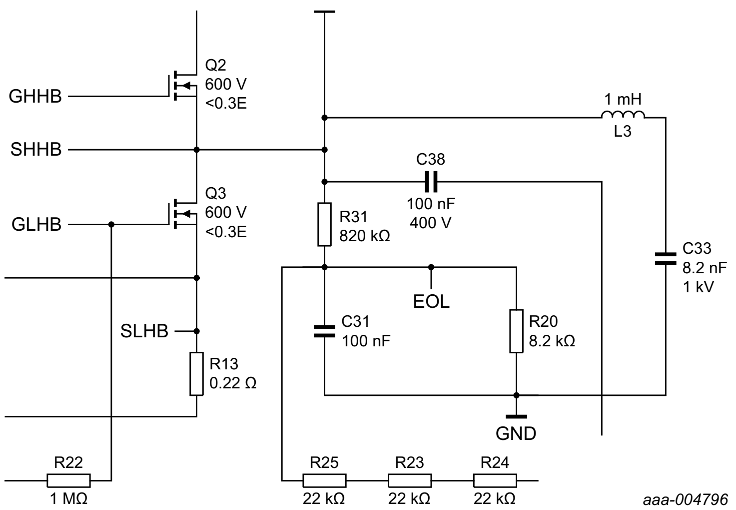


Fig 28. EOL rectification protection

The middle of the EOL window of 1.9 V is made with R31 and R20. If a lamp has no rectification, the current through R23 to R25 averages zero. If a lamp rectifies, the voltage over C31 changes. The lower the values of R23 to R25, the tighter the limit of the rectification protection.

4.8 Overpower protection

An easy way to achieve Overpower protection is to thermally attach an NTC to one of the half-bridge MOSFETs. If the half-bridge MOSFET runs too hot, a small signal MOSFET then pulls VFB down to ground. If VFB is under 200 mV, the ballast goes to standby.

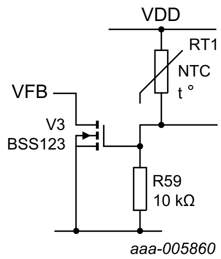


Fig 29. Overpower protection

4.9 Bill of material (BOM) of the four 18 W lamp inductive topology

The BOM of this inductive heating solution is lower than the VDR solution. The magnetic component costs are lower, with one large inductor being about the price of two small ones. The heating transformer is also very cheap/small, being similar to the one in a 15 W CFL.

However, a lot more small signal components are required in the inductive heating design than in the ceramic disk or VDR design. These components are not expensive but do increase the cost of manufacturing, especially when no SMD components are used.

Using SMD components, with resistors 0.01 Dollar cent each and capacitors less than a cent, keeps the total BOM cost low. However, an automatic pick and place facility must be present for SMD components.

The preheat time and BEF of this inductive topology enables it to outperform a topology with a capacitor across the filaments. Producing a good preheat of 0.7 s and a good BEF at the same time is no problem.

Use 2 kV capacitors for the first prototypes. When the protections do not work, the voltage on the resonant tank can easily rise to above 2 KV.

Choose high quality resonant tank capacitors (higher than for CFL) for the production version. The voltage across the capacitors is about 300 V RMS during lamp operation. Too-high dielectric losses reduce the BEF and the spread in capacitor values results in a spread in the lamp discharge current.

The 100 pF lamp current detection capacitor (C12 in Figure 30) must be from the same manufacturer/series as the capacitors that regulate the lamp discharge current. This requirement is because their temperature characteristics must match.

4.10 Complete four 18 W lamps schematic

Figure 30 and Figure 31 show the complete four 18 W lamps schematic.

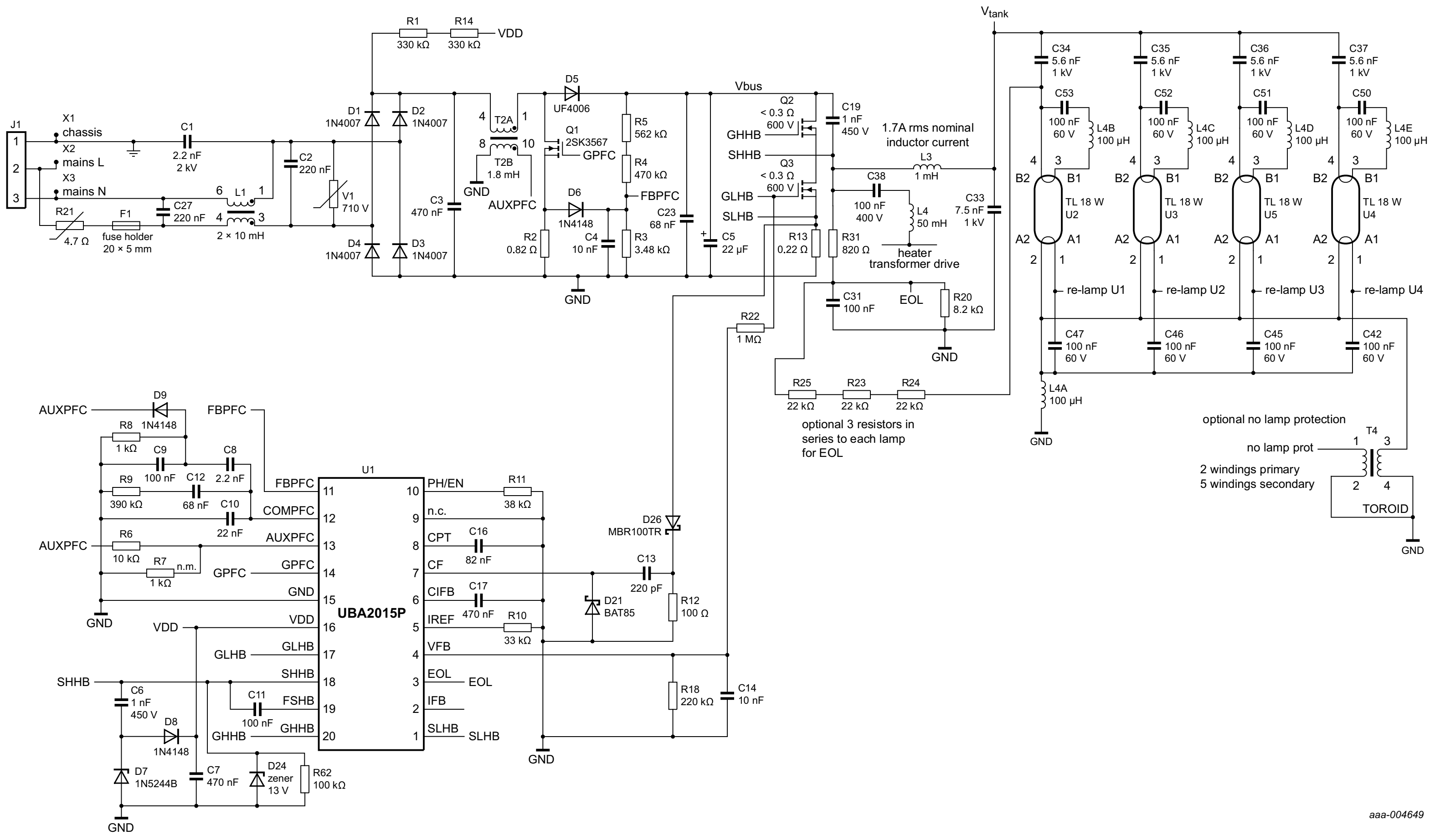


Fig 30. Complete four 18 W lamp schematic 1

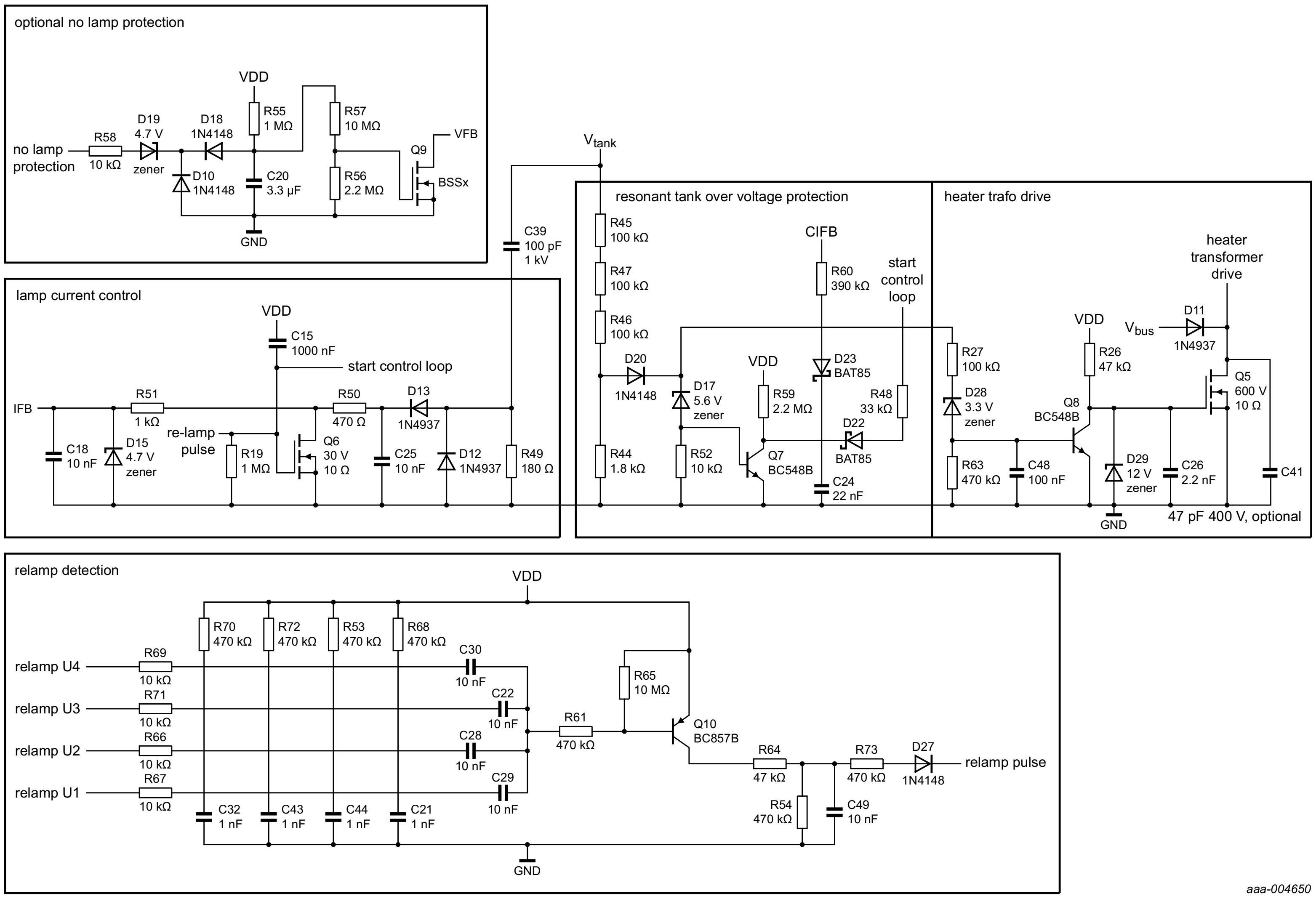


Fig 31. Complete four 18 W lamp schematic 2

5. Separate heating transformer combined with passive PFC for two 36 W T8 lamps

The topology described in Section 4 can also be used in combination with passive PFC. The passive PFC topology in this example is the improved valley fill (IVF). It is combined with a charge pump to keep the mains harmonic distortion within limits. A common mode transformer and EMI inductor can be added (not required in all countries).

More details on the IVF design can be found in the NXP user manual (xxx..note to editor, about to be on Web).

The working principle of this design is the same as with PFC, therefore only the differences related to the passive PFC are described.

5.1 IVF circuit with charge pump

The IVF circuit consists of C4, C16 and D5 to D8. The valley voltage, normally only half the peak of the mains voltage, is pumped up from 150 V to about 210 V. This increase is achieved using the connection of D6 and D. There is a voltage mode charge pump that consists of capacitor C7 with diodes D1 and D2.

5.2 Resonant tank

The bus voltage in the IVF topology can be as low as 130 V (DC) (at AC mains 160 V). This voltage is much lower than the PFC voltage of 400 V in the earlier example.

To avoid any resonant tank becoming capacitive at low bus voltages, the inductor is kept small and the resonant capacitor large. If the mains voltage is 180 V (AC), a valley fill topology requires a minimum capacitance of 10 nF to avoid hard switching in the valley. A typical requirement for electronic ballasts is proper operation between 180 V (AC) and 270 V (AC) mains.

Putting this 10 nF capacitor through the filaments of a T8 36 W burner results in 280 mA capacitive current. This current produces a too-high SoS and a consequent too-low BEF.

The circuit from topology 6 allows a resonant tank with the capacitor not through the filament but still providing ILO.

The resonant tank also consists of two charge pump capacitors that are a part of the coupling between the resonant tanks. These capacitors increase the valley voltage and the power factor while reducing the THD.

If only an inductor/capacitor combination is used, as in the earlier example with PFC, the half-bridge MOSFET current is much larger (1.8 A RMS). Thus, requiring more expensive MOSFETs.

As with all passive PFC topologies, leaving out the PFC section while still requiring a good power factor and crest factor comes with a price. This topology requires a larger MOSFET current through the half-bridge.

5.3 Relamp and start-up

You can add V_{DD} start-up resistors in parallel through the upper filaments, or leave out the electrode capacitors C48 and C50 (see Figure 32). The relamp circuit is the same as in the example with PFC.

The UBA2017 is part of the UBA2015 family, the only major difference is that the PFC section is absent. As a result, the IC is available in the 16-pin DIP16 and SO16 instead of the 20-pin UBA2015.

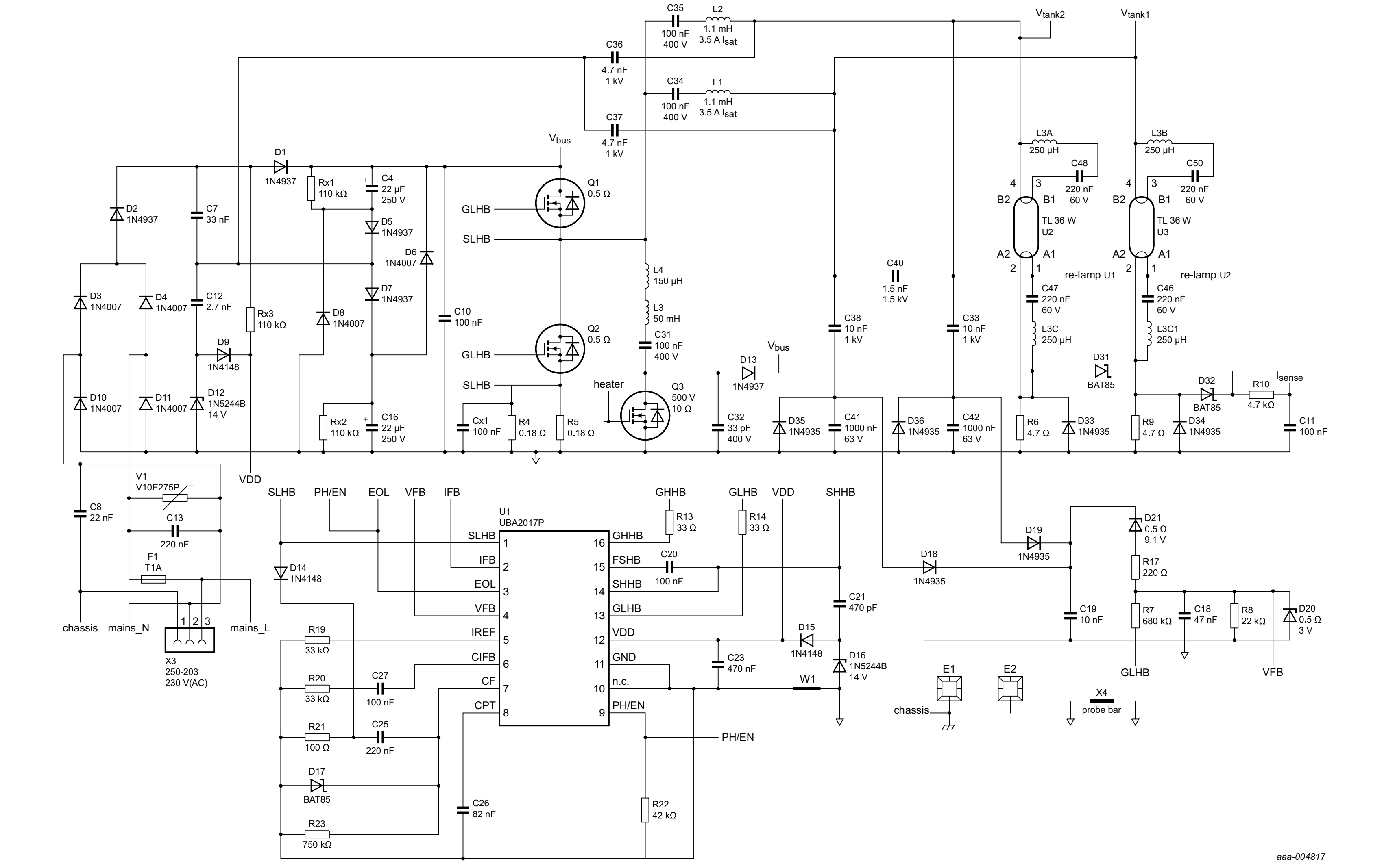


Fig 32. Large signal path

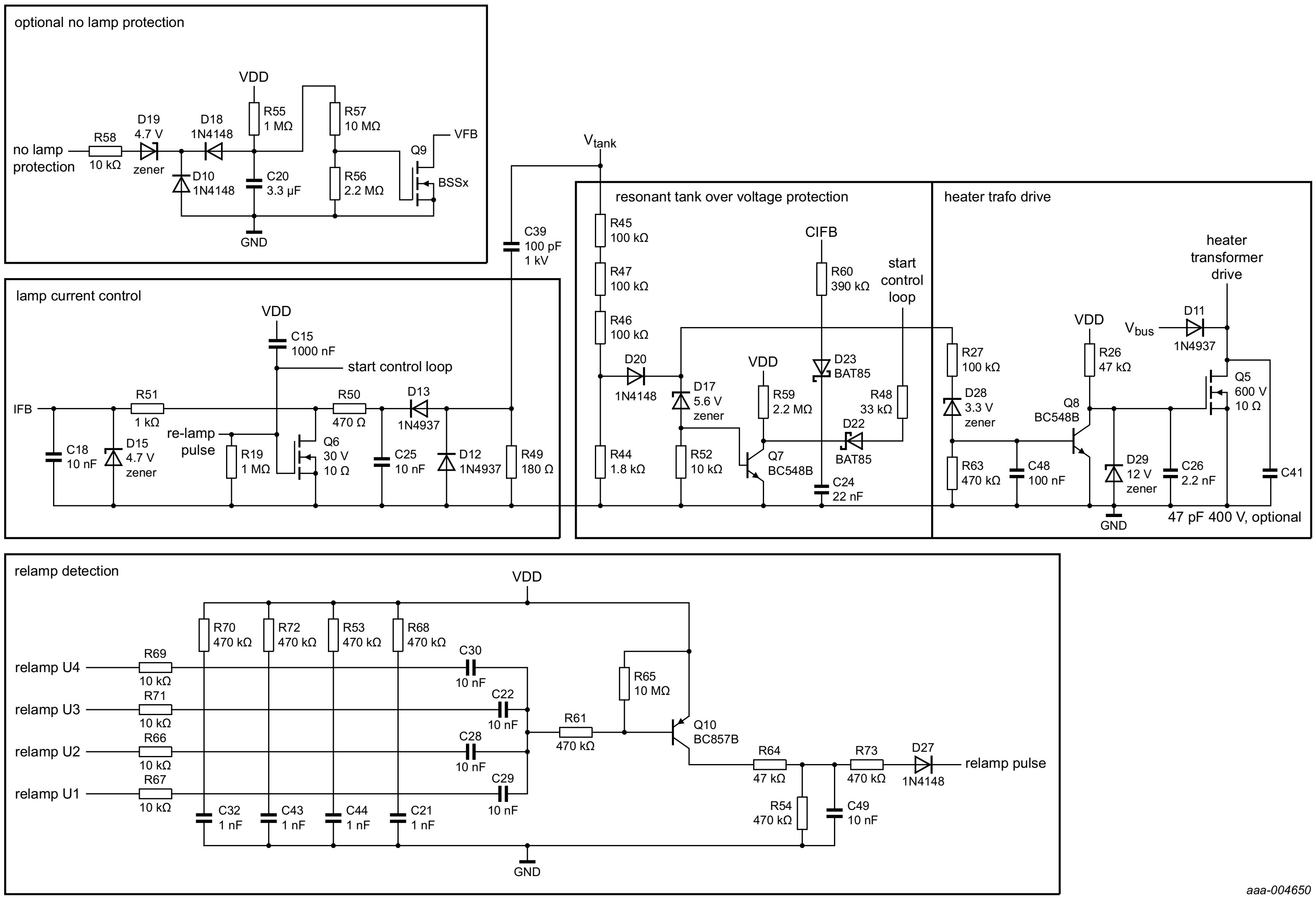


Fig 33. Heater and feedback control

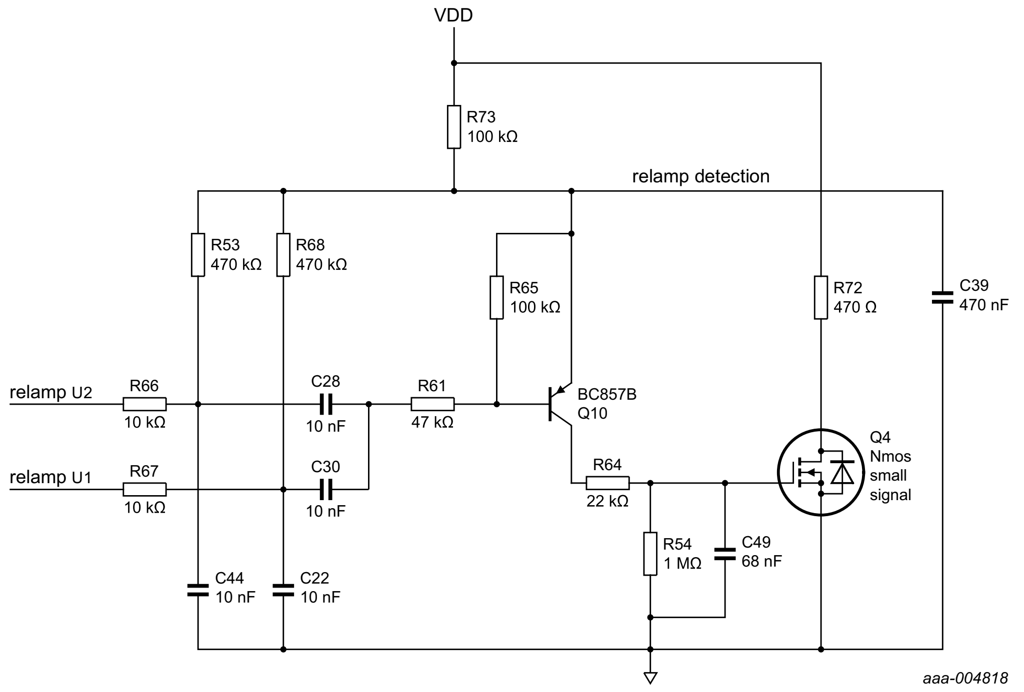


Fig 34. Relamp detection 2

6. Glossary

Independent lamp operation (ILO) — A multilamp electronic ballast allows working lamps to operate even when there are missing or broken filaments in any of the other lamps in the ballast. If the lamps are in series and one of them fails, all the lamps in the same series branch are off. But, a four lamp ballast with two times two lamps in series can still have ILO.

Relamp — The requirement that a ballast restarts itself automatically after a lamp has been (re)placed. If the ballast was already running, the newly inserted lamp must ignite without requiring a power cycle.

Legal requirements — There are many legal requirements for TL ballasts. One that affects ILO is the maximum voltage over the TL connection pins during lamp operation. This requirement means that some of the ILO topologies are not allowed in certain countries. The most commonly used topology in the US is to generate a high voltage greater than the ignition with a transformer. This topology cannot be used in Europe where only a limited voltage over the contacts is allowed after 5 s (*IEC 928 safety requirements, section 12*). This time includes any retry the ballast performs on no-ignition.

Preheat — A requirement for filament preheating makes some of the topologies unsuitable. The lamp type is also important because most T5 Hawaiian Electric Industries lamp types require inductive heating.

Ballast Efficacy Factor (BEF) — A minimum amount of light output given the consumed ballast power. BEF = Ballast factor / Input power.

End Of Life (EOL) — End-of-life conditions for lamps such as:

- Degauss - When the (starter) gasses leak out of the lamp. So although the filaments are present, the lamp does not ignite. This situation is rare, but it does happen.
- Rectification - When one of the filaments is broken or its emissive coating has vaporized.
- Symmetrical aging - When both filaments are broken or have lost their emissive coating.

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